Apollo's 50th Anniversary

Frank Slomka, Ulm University

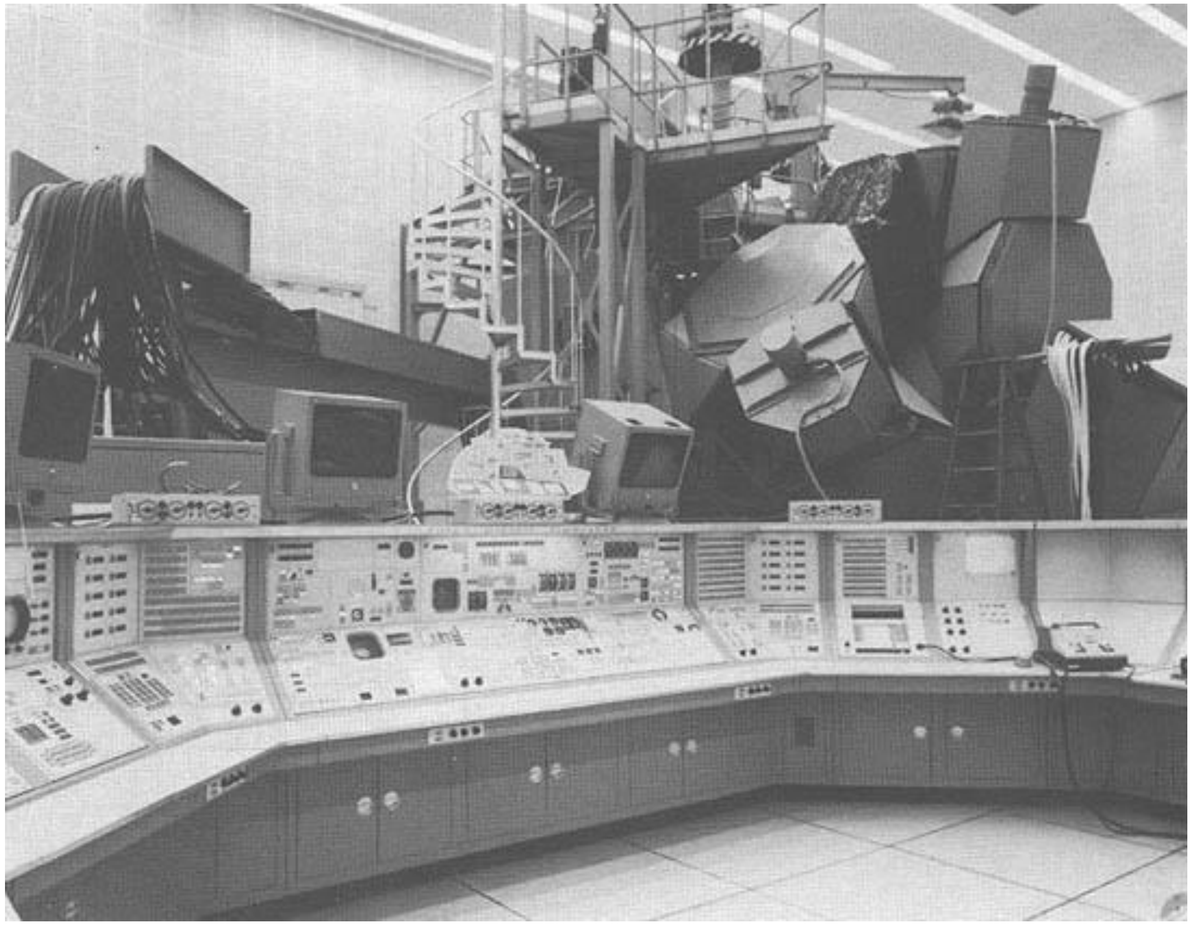
Source: Nasa

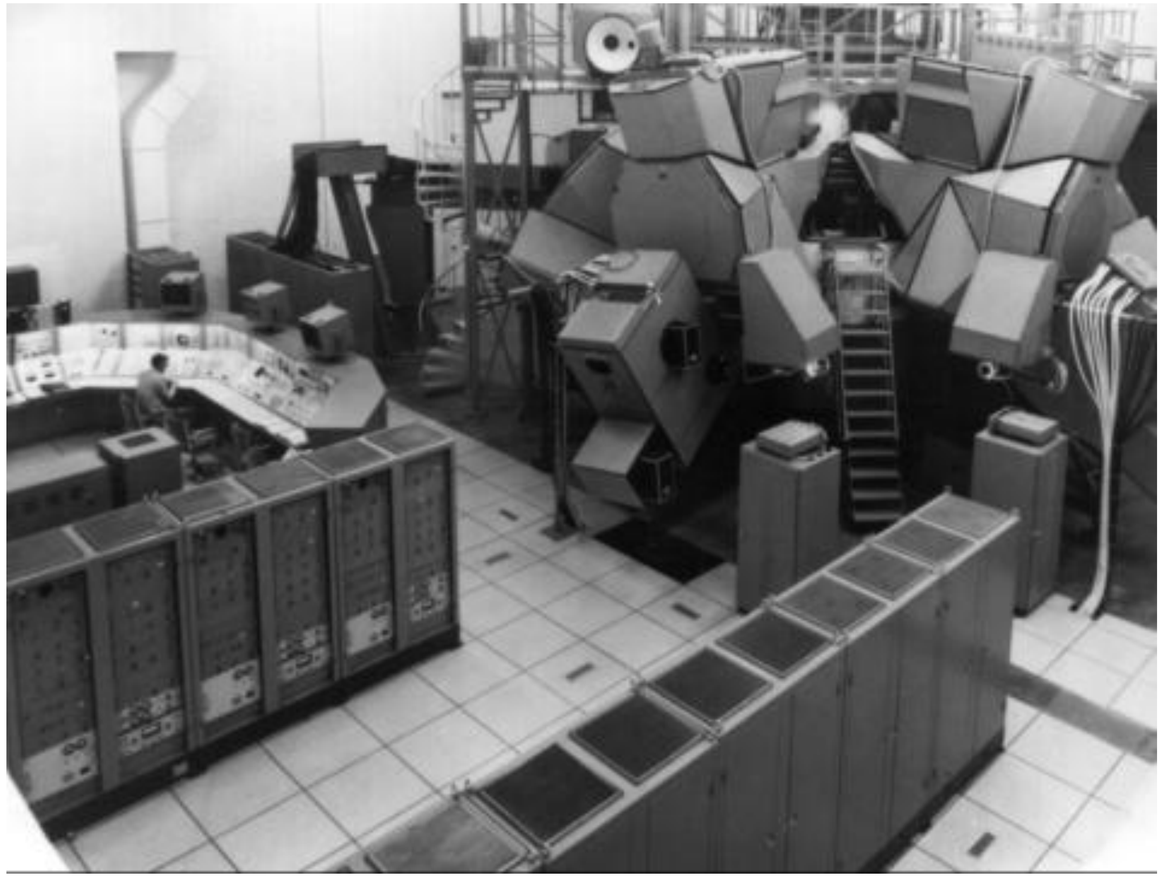
Apollo's 50th Anniversary

Frank Slomka, Ulm University

Teaching Embedded System Design
with Simscape and Simulink

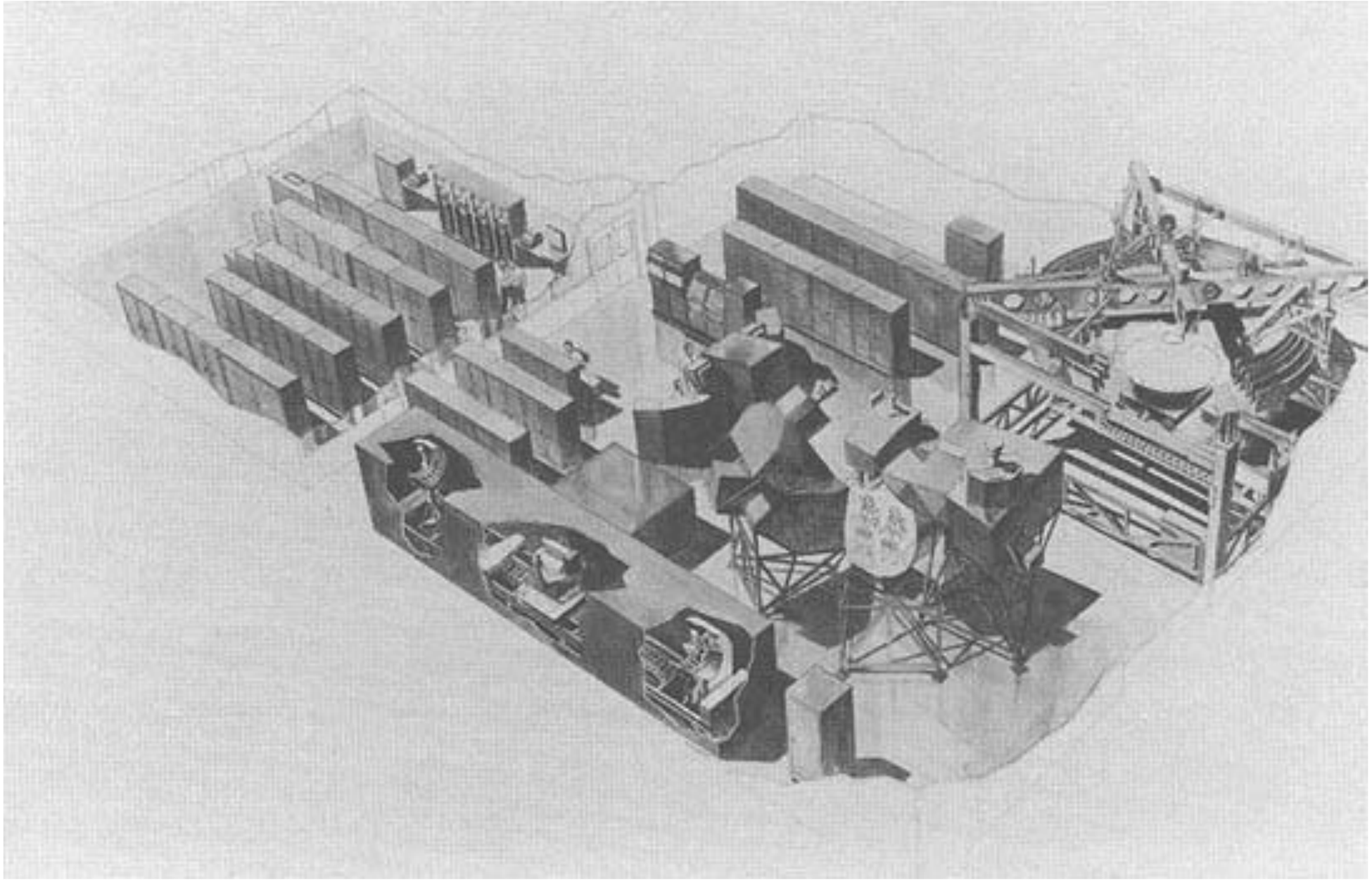
Computer Simulations





Source: Nasa

Computer Simulations

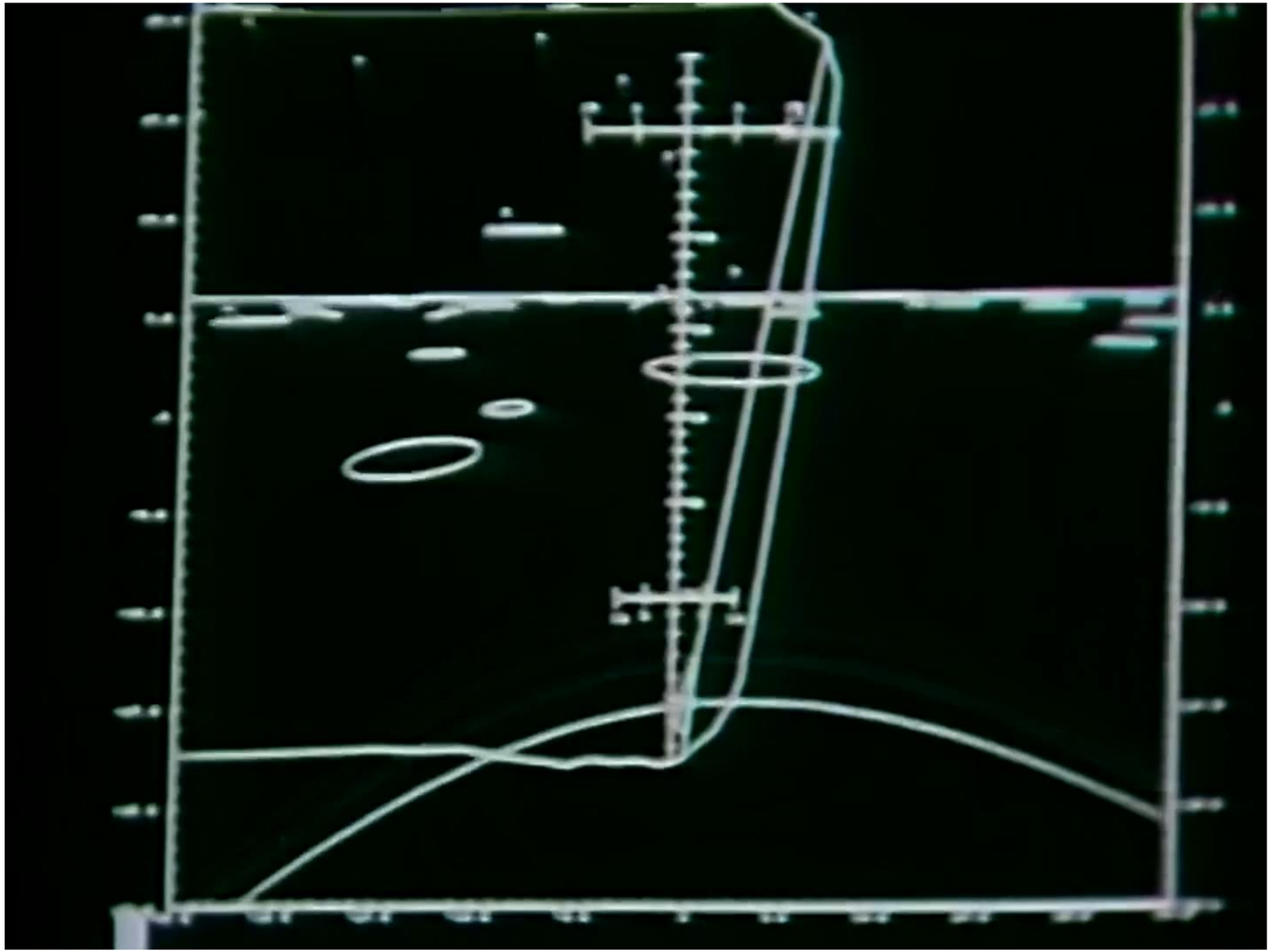


Source: Nasa

Computer Simulations

Source: Nasa

Computer Simulations



Source: Nasa

How to teach engineering?

Source: Pannel_2010, Flickr

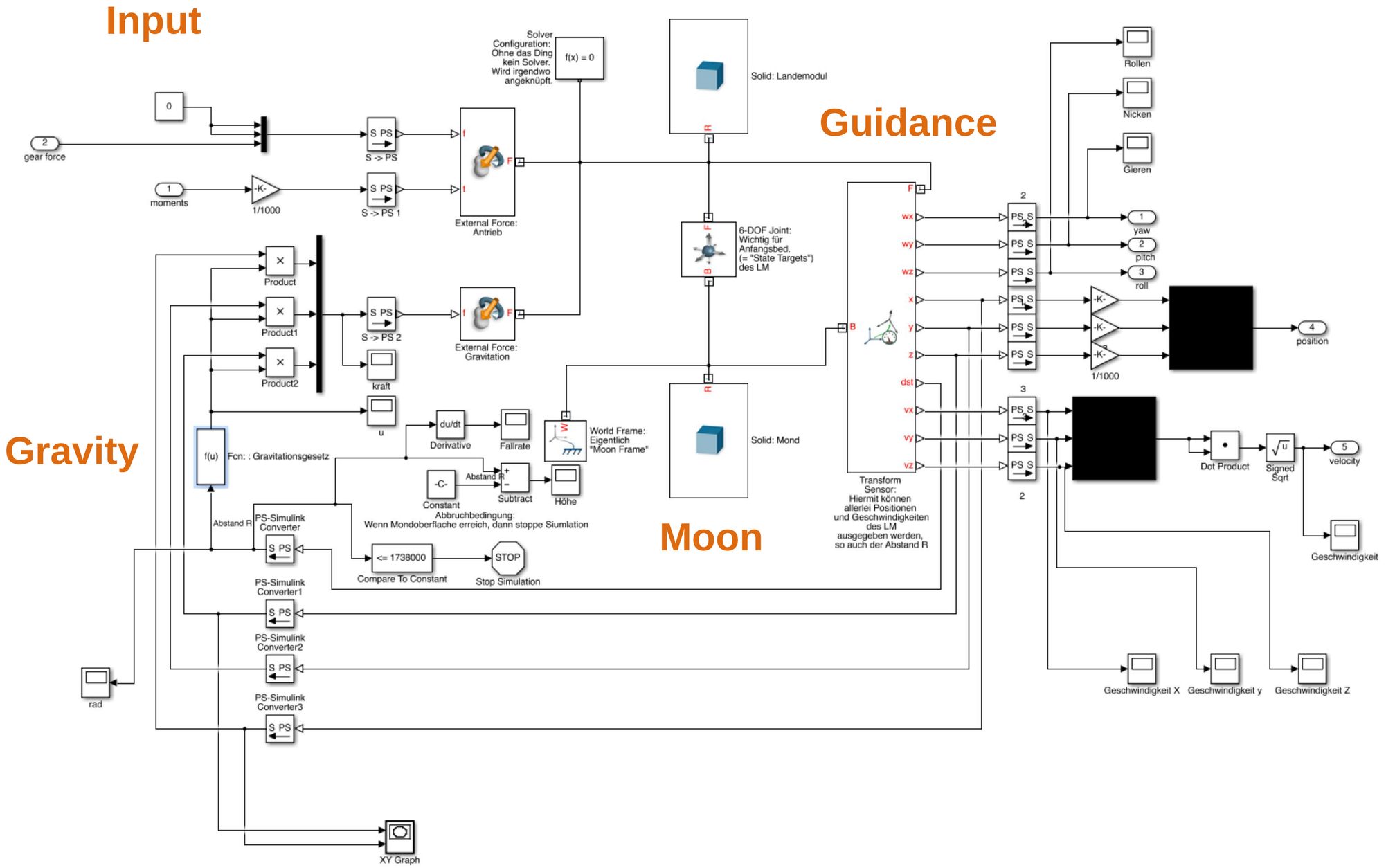
Build something!

Embedded Systems?

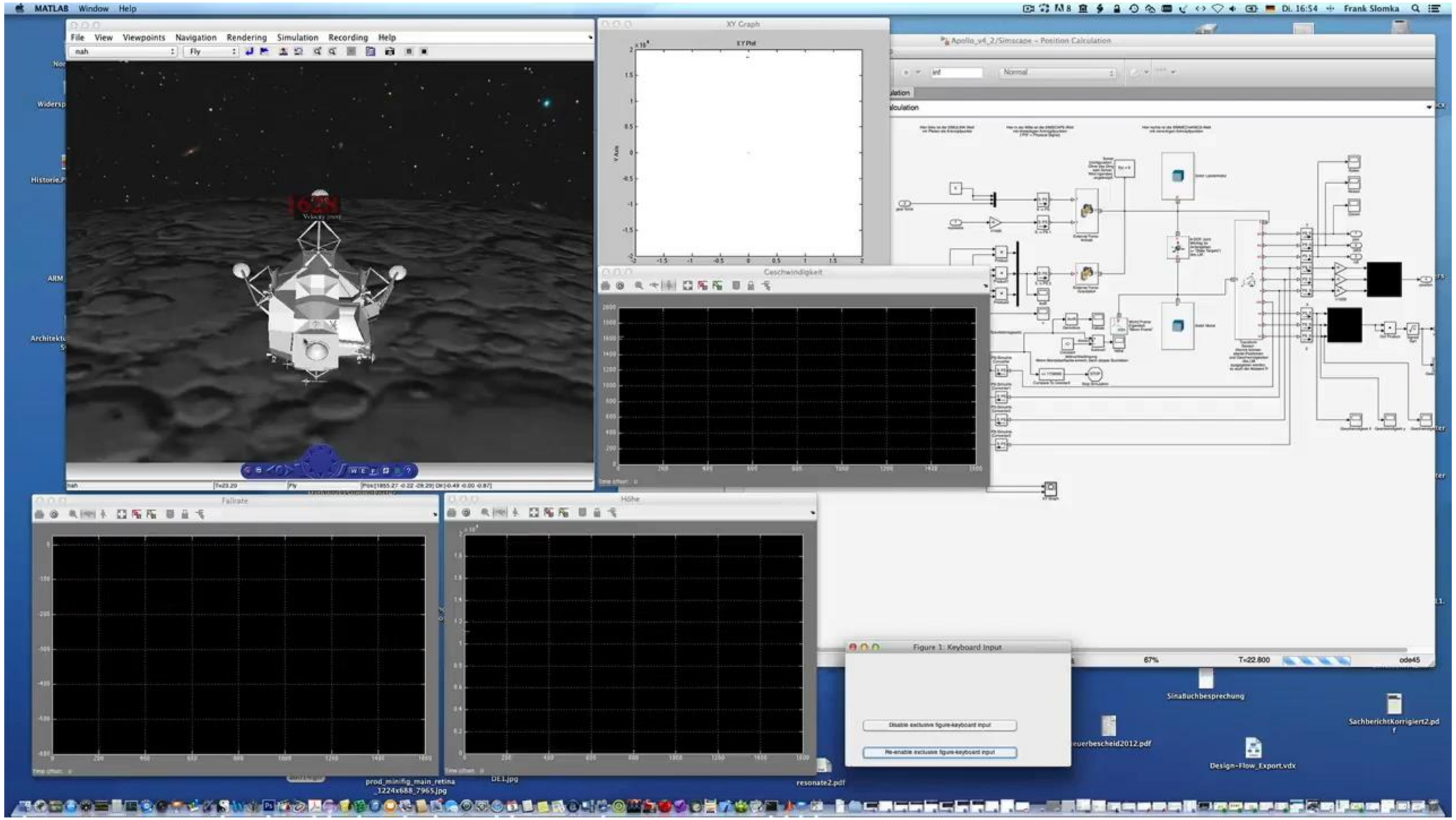
Source: Tyne and Wear Archives & Museums @ flickr.com

Moon landing
1. Try: Simscape

Lunar lander



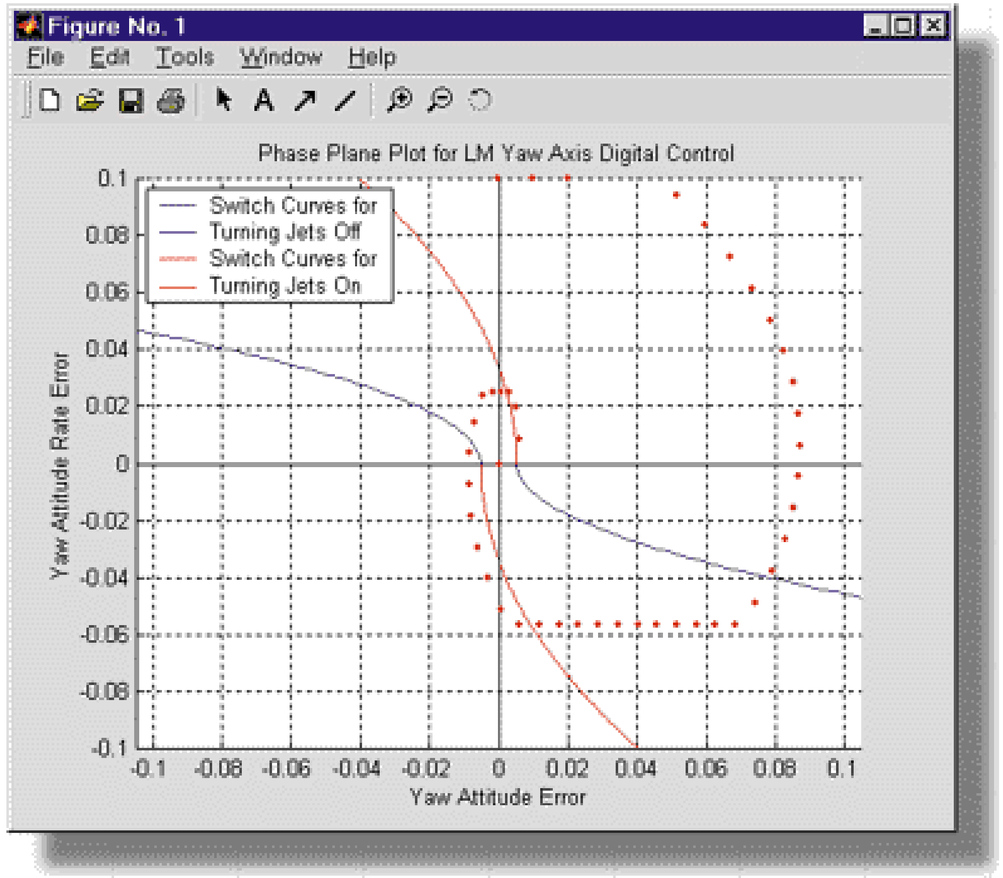
What about fuel?

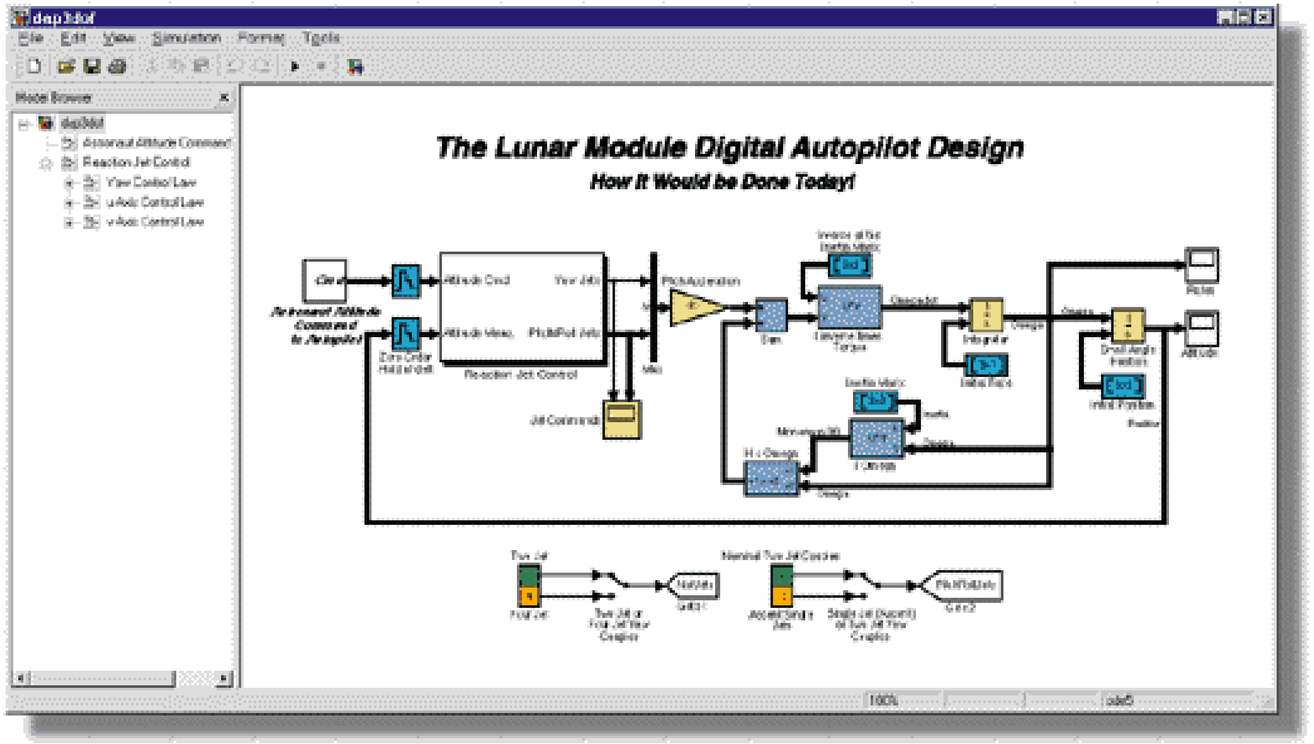


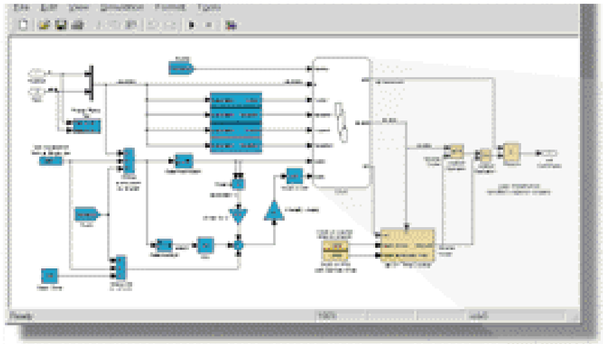
Moon landing
2. Try: Simulink

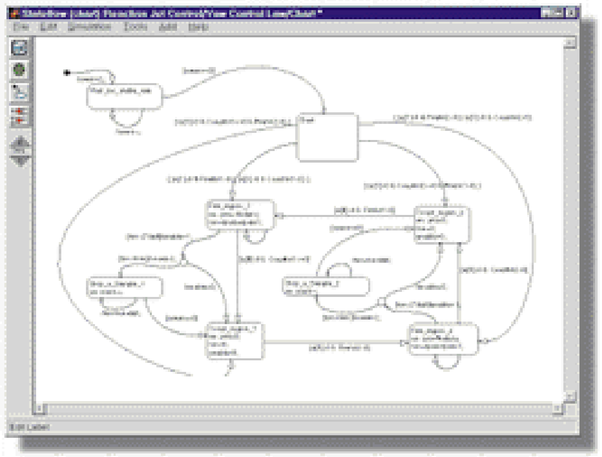
Fly me to the moon - Then an now

Richard J. Gran 30 years anniversary









1 h to model!

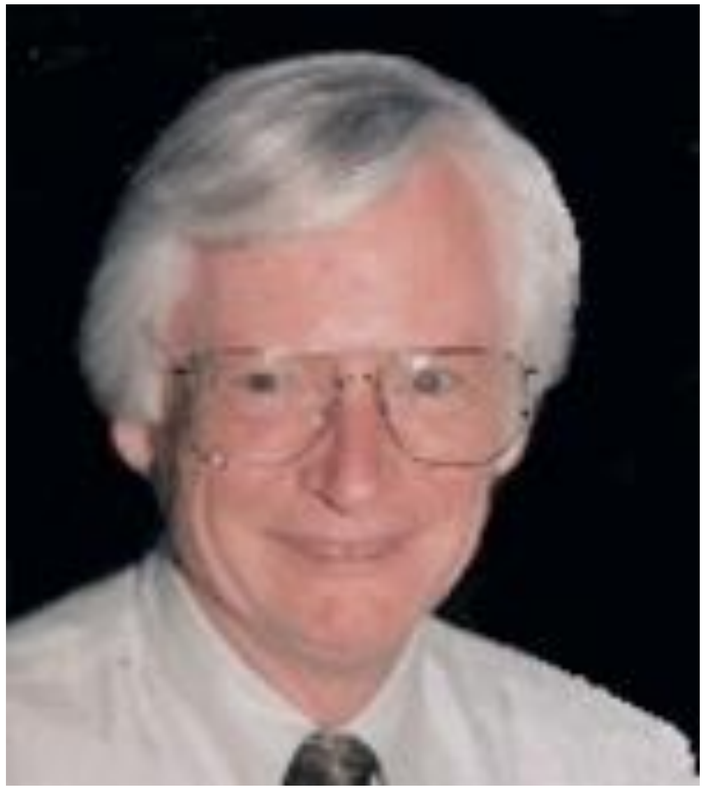
https://de.mathworks.com/company/newsletters/articles/fly-me-to-the-moon-then-and-now.html

Source: Mathworks

But:

That same year, I became a member of the Grumman Guidance and Control group and, as such, participated on field assignment, in the design of the Lunar Module digital autopilot at MIT Instrumentation Laboratories from 1963 to 1966.

Richard J. Gran



Source: Mathworks

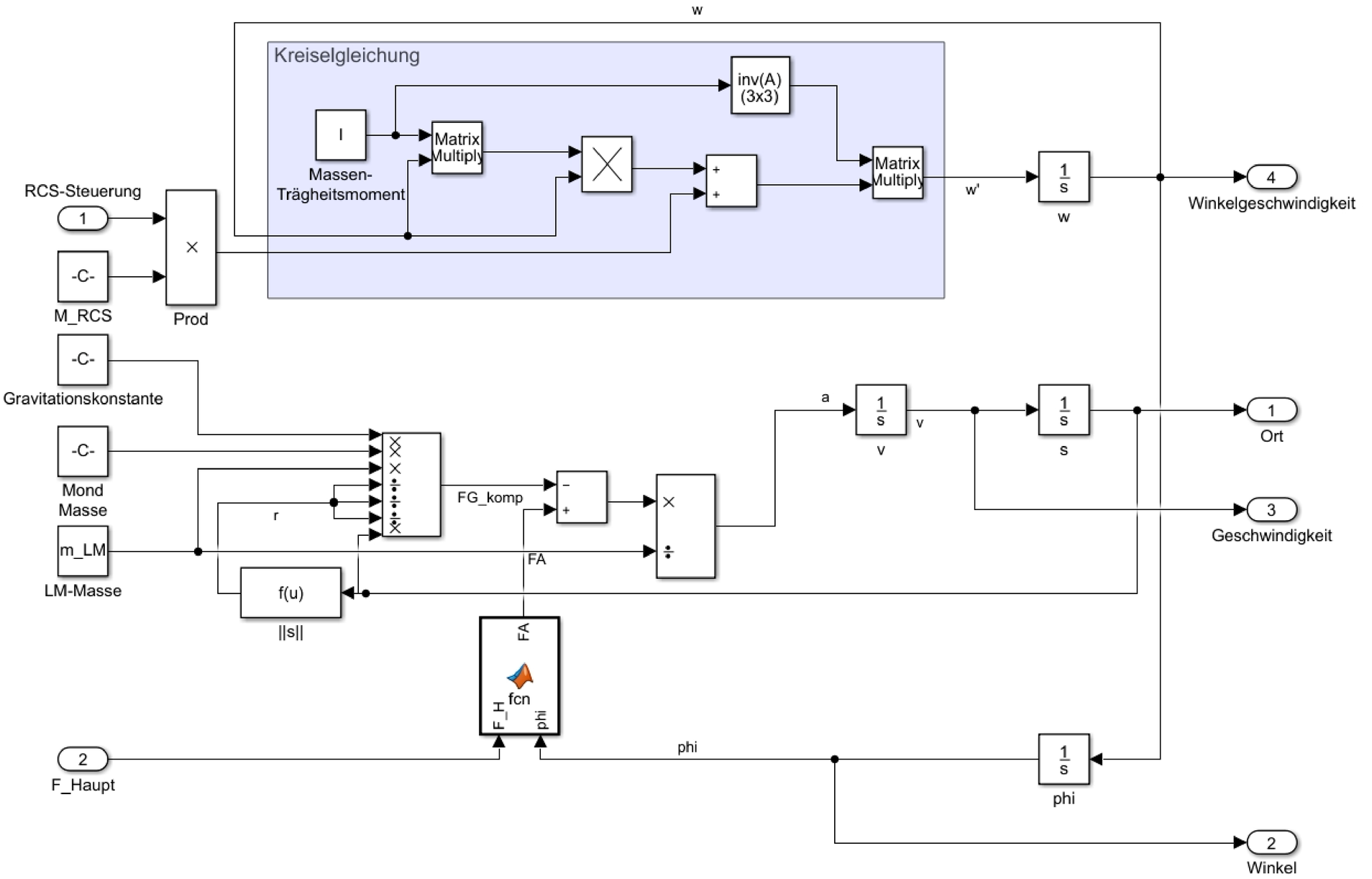
Source: Engineering and Technology History

How to solve complex technical problems….

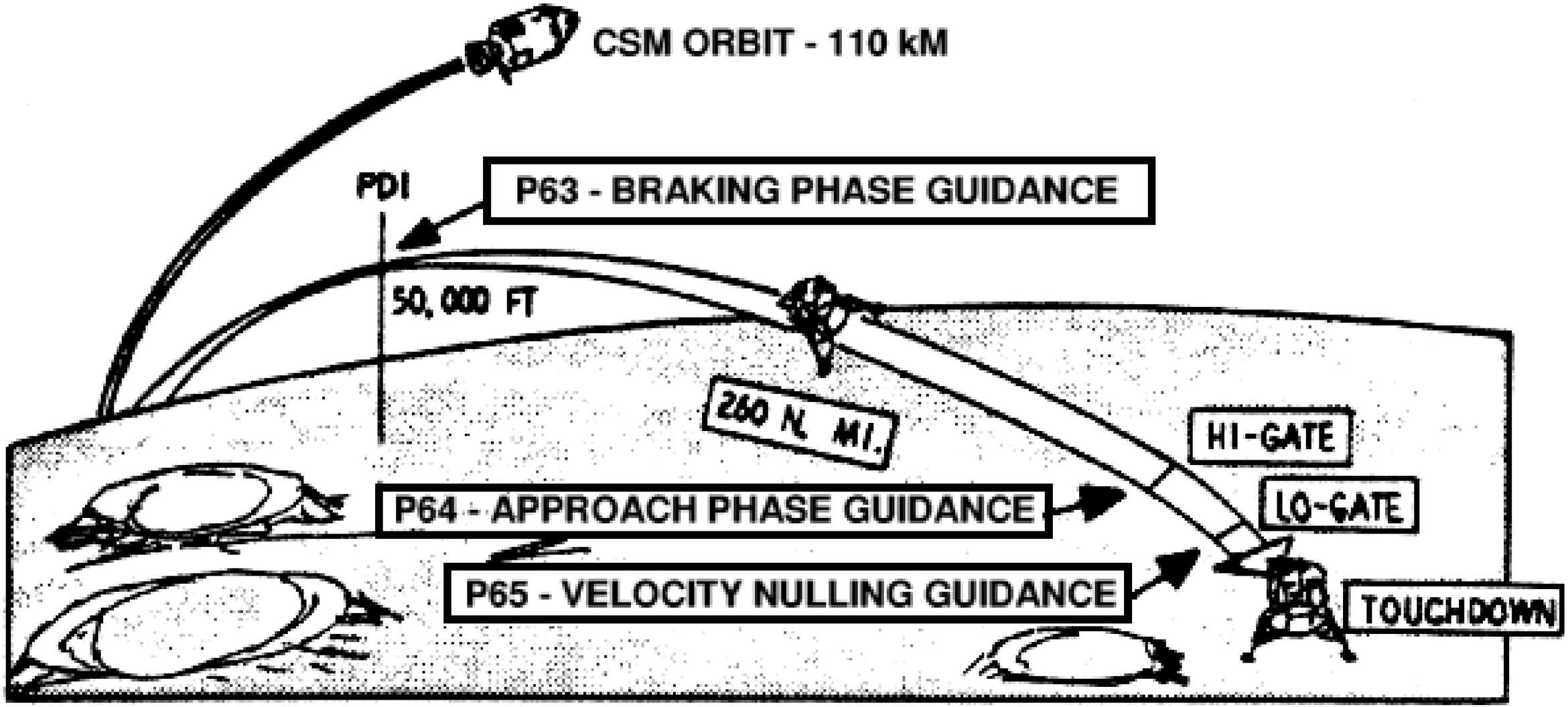
….if I know nothing!

Source: Pannel_2010, Flickr

Modeling

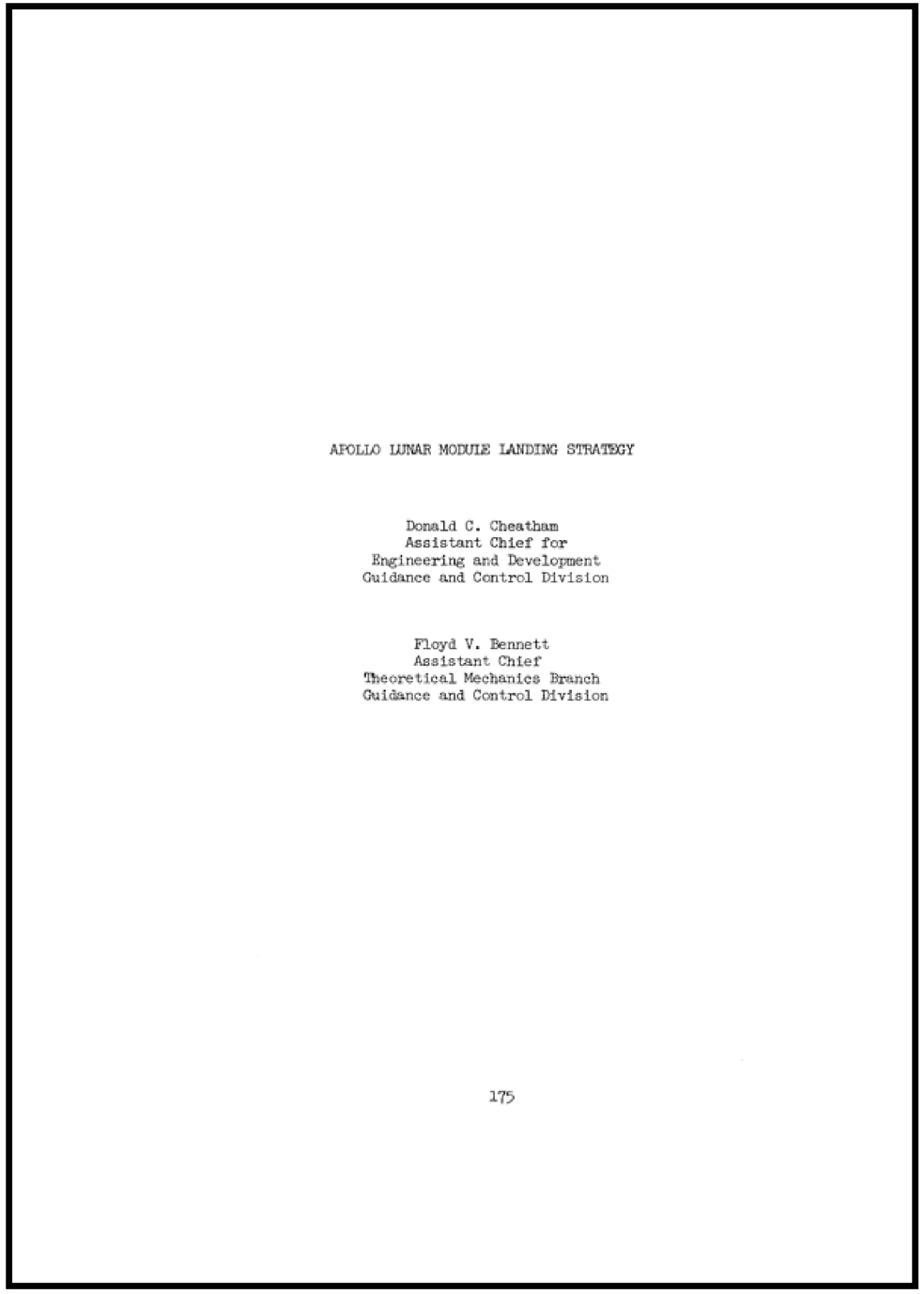

w
Kreiselgleichung
inv(A)
(3x3)
I
Massen-
Trägheitsmoment
Matrix
Multiply
Matrix
Multiply
w'
1
s
w
4
Winkelgeschwindigkeit
RCS-Steuerung
1
-C-
M_RCS
Prod
-C-
Gravitationskonstante
-C-
Mond
Masse
m_LM
LM-Masse
r
FG_komp
FA
f(u)
||s||
a
1
s
v
v
1
s
s
1
Ort
3
Geschwindigkeit
FA
fcn
F_H
phi
2
F_Haupt
phi
1
s
phi
2
Winkel

Build a model is one thing…



…but how to land?

Source: Nasa



APOLLO LUNAR MODULE LANDING STRATEGY

Donald C. Cheatham
Assistant Chief for
Engineering and Development
Guidance and Control Division

Floyd V. Bennett
Assistant Chief
Theoretical Mechanics Branch
Guidance and Control Division

175

Source: Nasa

Astronauts fail on landing by hand

A NASA team of 10 people did simulations 2 years!

…but how to land?

LM POWERED DESCENT

ENGINE IGNITION
h=50,000 FT
ϕ=86°
T=0 SEC
V=5500 FT/SEC
γ=0°

MAXIMUM THROTTLE
h=50,000 FT
ϕ=88°
T=28 SEC
V=5564 FT/SEC
γ=−.2°

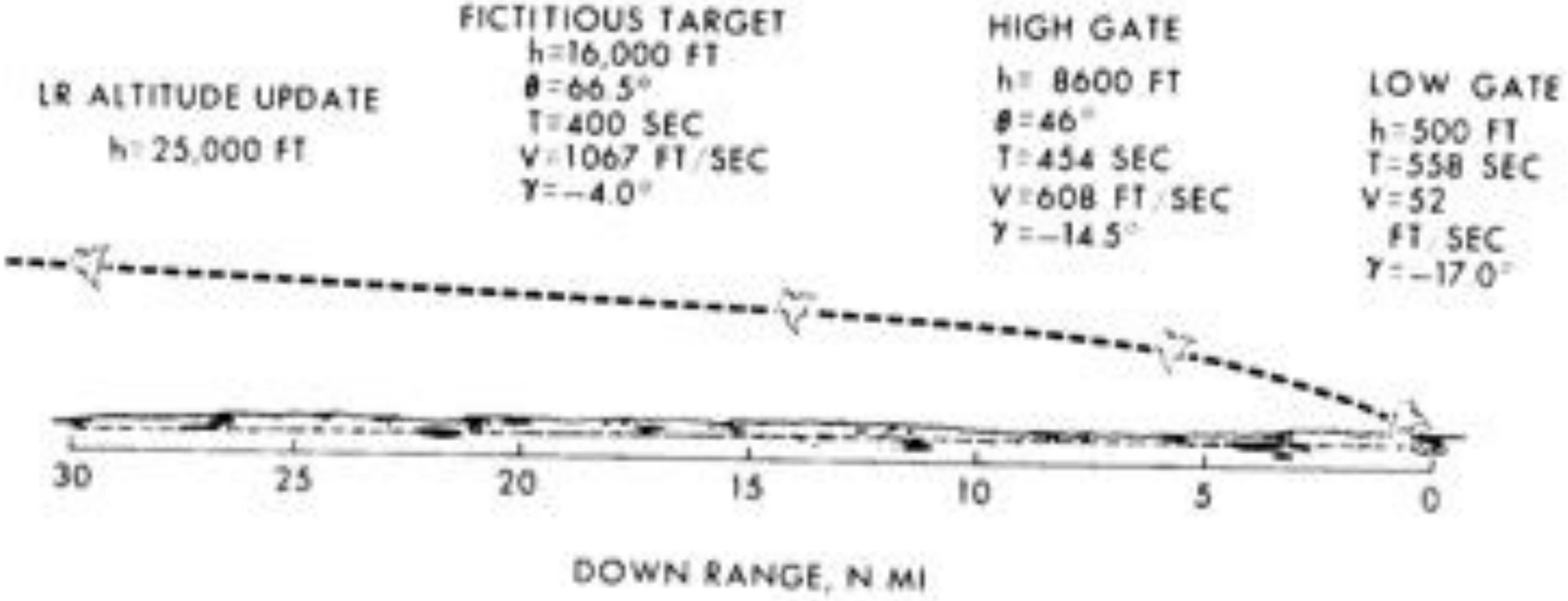
TARGET SWITCHOVER
h=43,000 FT
ϕ=80°
T=228 SEC
V=3385
γ=−1.4°

LR ALTITUDE UPDATE
h=25,000 FT
ϕ=71°
T=328 SEC
V=2164 FT/SEC
γ=−4.0°

…but how to land?

Source: Nasa

LM POWERED DESCENT (CONT)

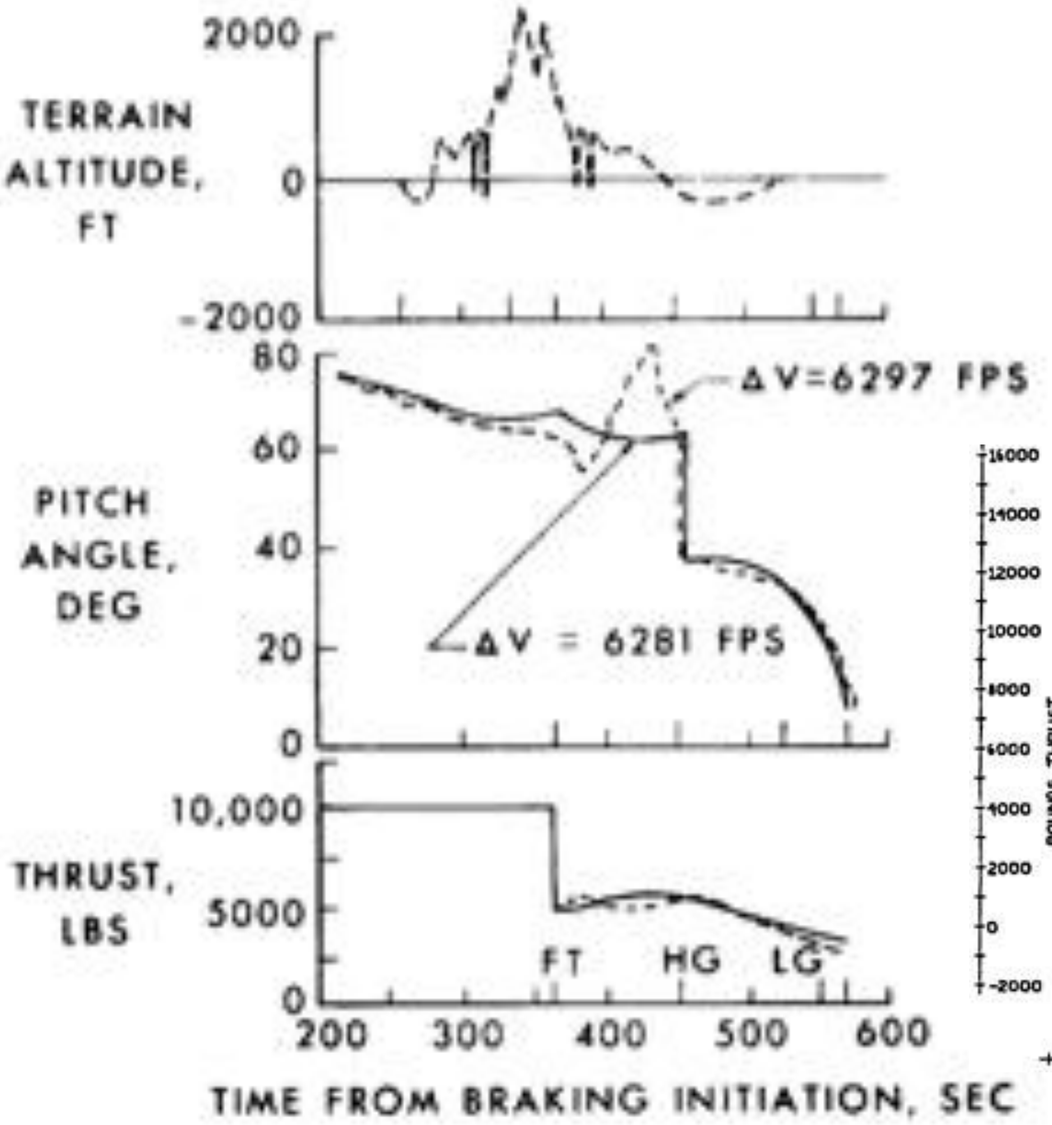


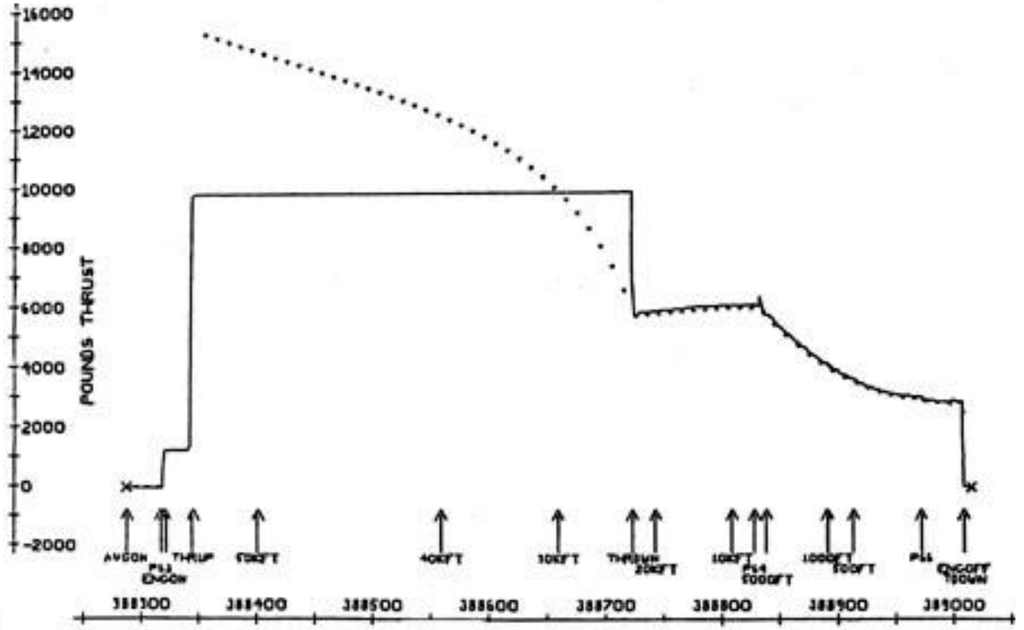
…but how to land?

Source: Nasa

NASA-S-66-6515 JUN

GUIDANCE COMMANDS FOR POWERED DESCENT





IDEAL CONDITION ——

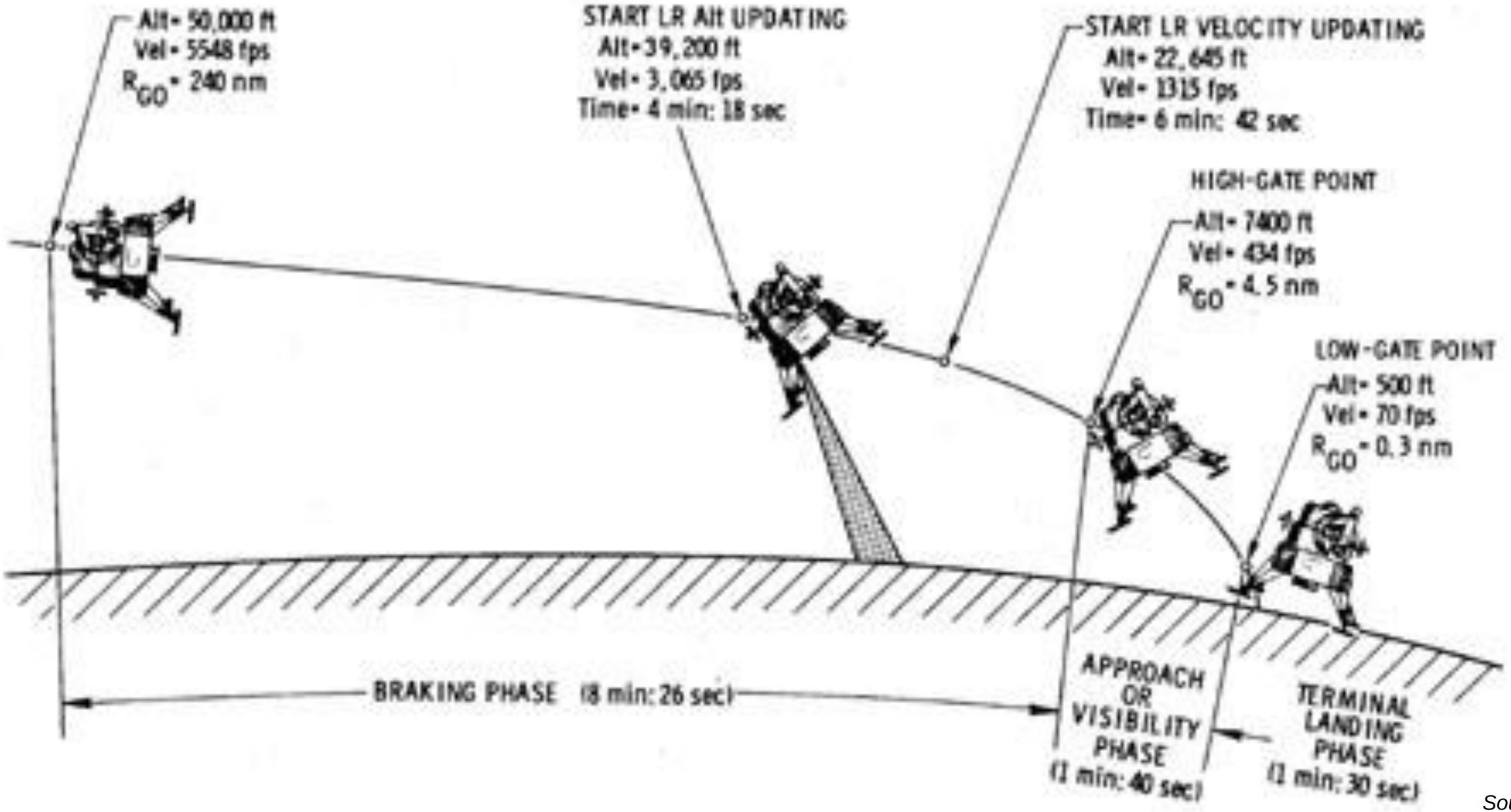
TYPICAL ERROR CONDITIONS AND TERRAIN - - - - -

FIGURE 25

…but how to land?

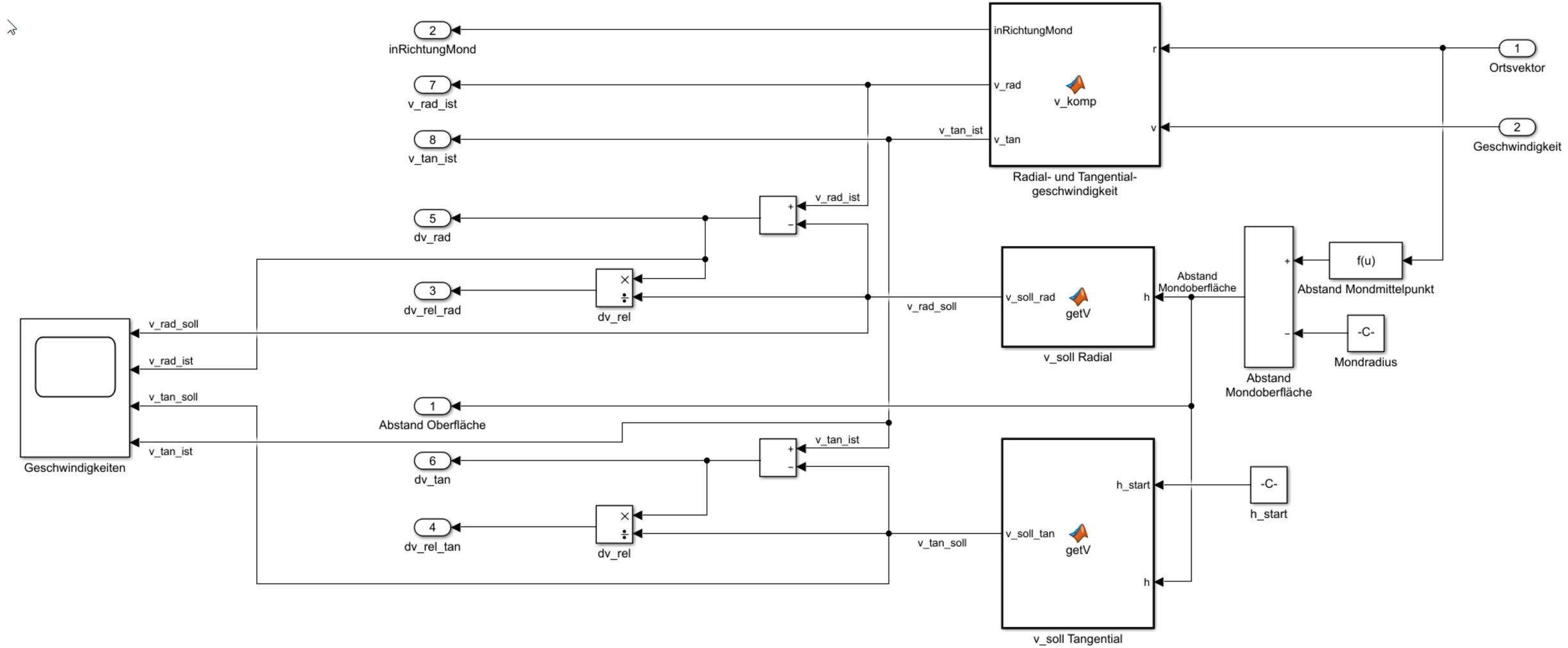
Source: Nasa

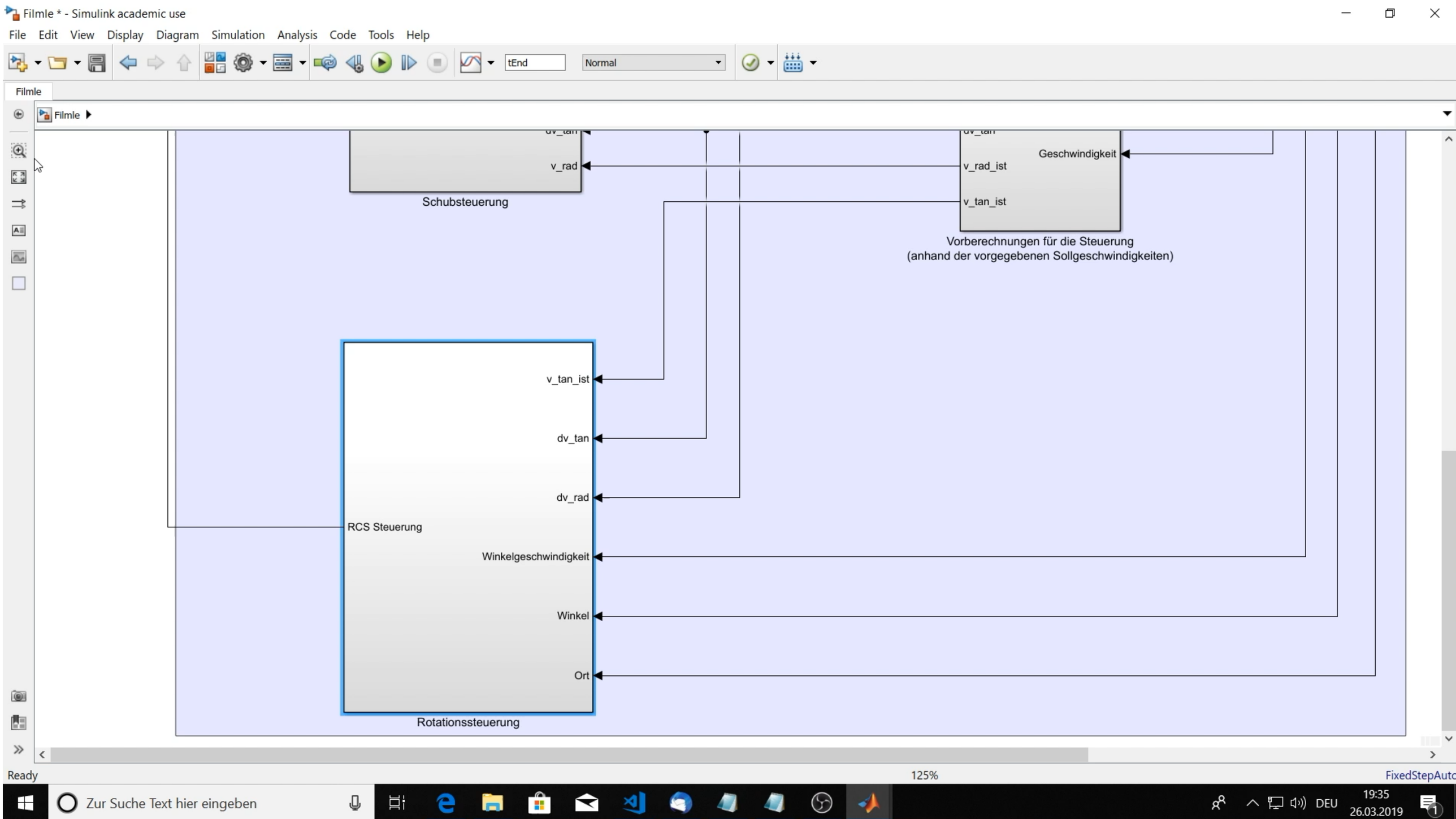
That way!



Source: Nasa

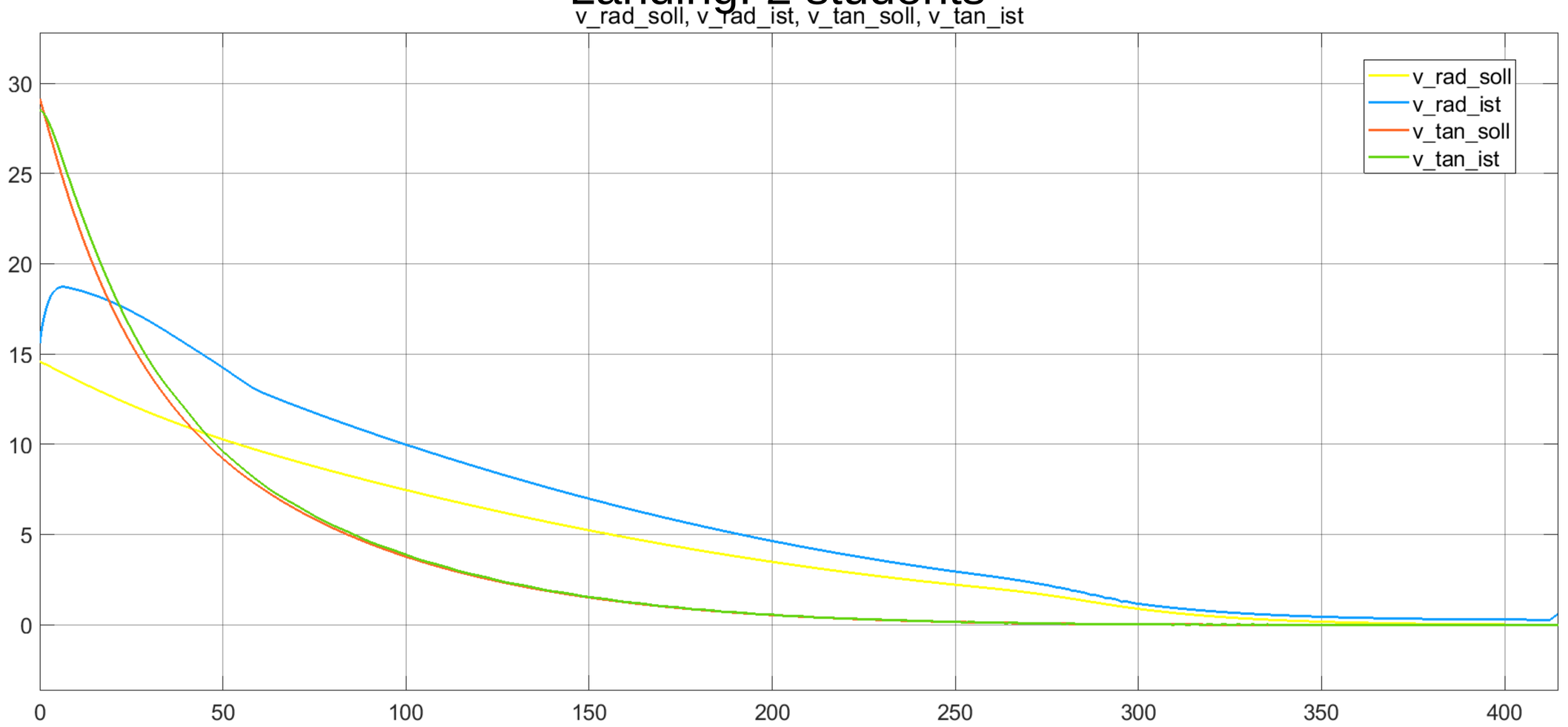
The result:


2
inRichtungMond
7
v_rad_ist
8
v_tan_ist
5
dv_rad
3
dv_rel_rad
dv_rel
v_rad_soll
v_rad_ist
v_tan_soll
v_tan_ist
Geschwindigkeiten
1
Abstand Oberfläche
6
dv_tan
4
dv_rel_tan
dv_rel
v_rad_ist
v_tan_ist
v_rad_soll
v_tan_soll
inRichtungMond
v_rad
v_tan_ist
v_tan
v_komp
r
v
Radial- und Tangential-geschwindigkeit
v_soll_rad
getV
h
v_soll Radial
Abstand Mondoberfläche
f(u)
Abstand Mondmittelpunkt
-C-
Mondradius
Abstand Mondoberfläche
v_soll_tan
getV
h_start
h
v_soll Tangential
-C-
h_start
1
Ortsvektor
2
Geschwindigkeit


Filmle * - Simulink academic use
File Edit View Display Diagram Simulation Analysis Code Tools Help
tEnd
Normal
Filmle
Filmle
v_rad
Schubsteuerung
Geschwindigkeit
v_rad_ist
v_tan_ist
Vorberechnungen für die Steuerung
(anhand der vorgegebenen Sollgeschwindigkeiten)
v_tan_ist
dv_tan
dv_rad
RCS Steuerung
Winkelgeschwindigkeit
Winkel
Ort
Rotationssteuerung
Ready
125%
FixedStepAuto
Zur Suche Text hier eingeben
DEU
19:35
26.03.2019

The result

- Simscape: 2 students
- Simulink model: 1 students
- Landing: 2 students



COMPUTER PROGRAM
P63

They want 'Delta-H',
which compares the
radar's and computer's
value for height.

Der 1202 Program-Alarm!

102:38:21 Armstrong: Sure do. Houston, (I hope) you're looking at our Delta-H.

102:38:25 Duke: That's affirmative.

102:38:26 Armstrong: (With the slightest touch of urgency) Program Alarm.

102:38:28 Duke: It's looking good to us. Over.

102:38:30 Armstrong: (To Houston) It's a 1202.

102:38:32 Aldrin: 1202. (Pause)

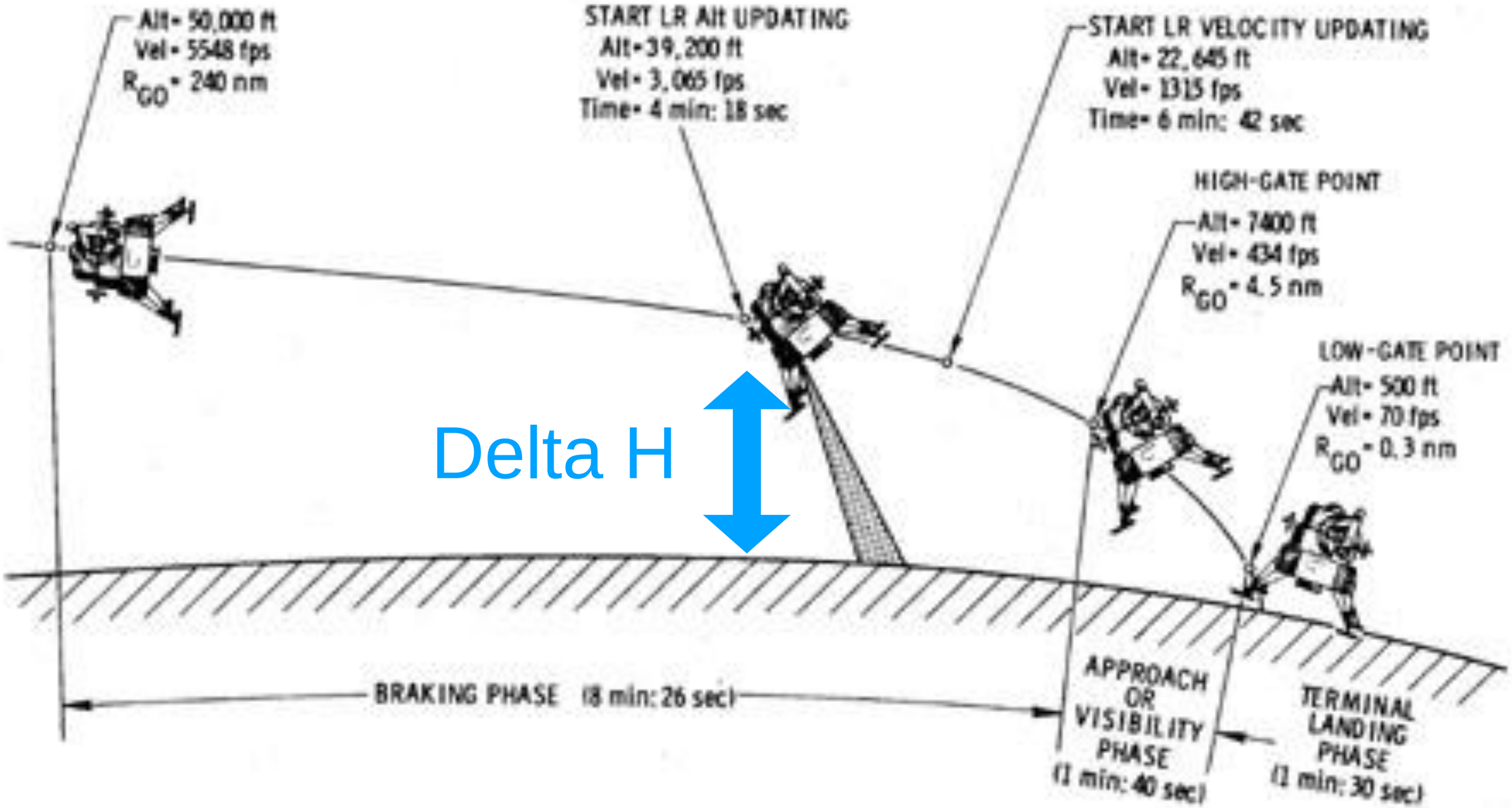
102:38:42 Armstrong (onboard): (To Buzz) What is it? Let's incorporate. (To Houston) Give us a reading on the Program Alarm.

102:38:53 Duke: Roger. We got you...(With some urgency in his voice) We're Go on that alarm.

Audio 7:30:

Audio Landung XX:

Program Delta H

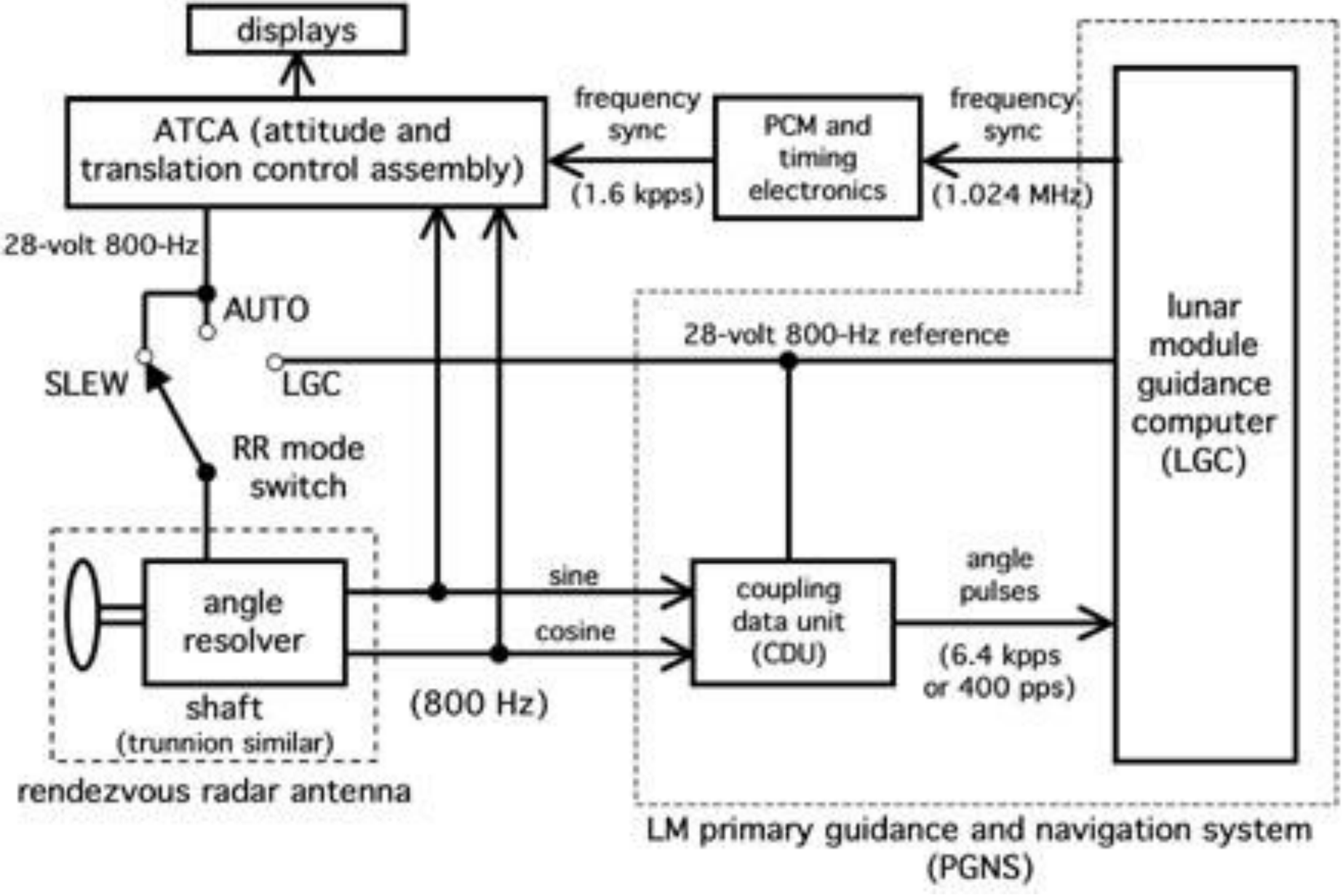


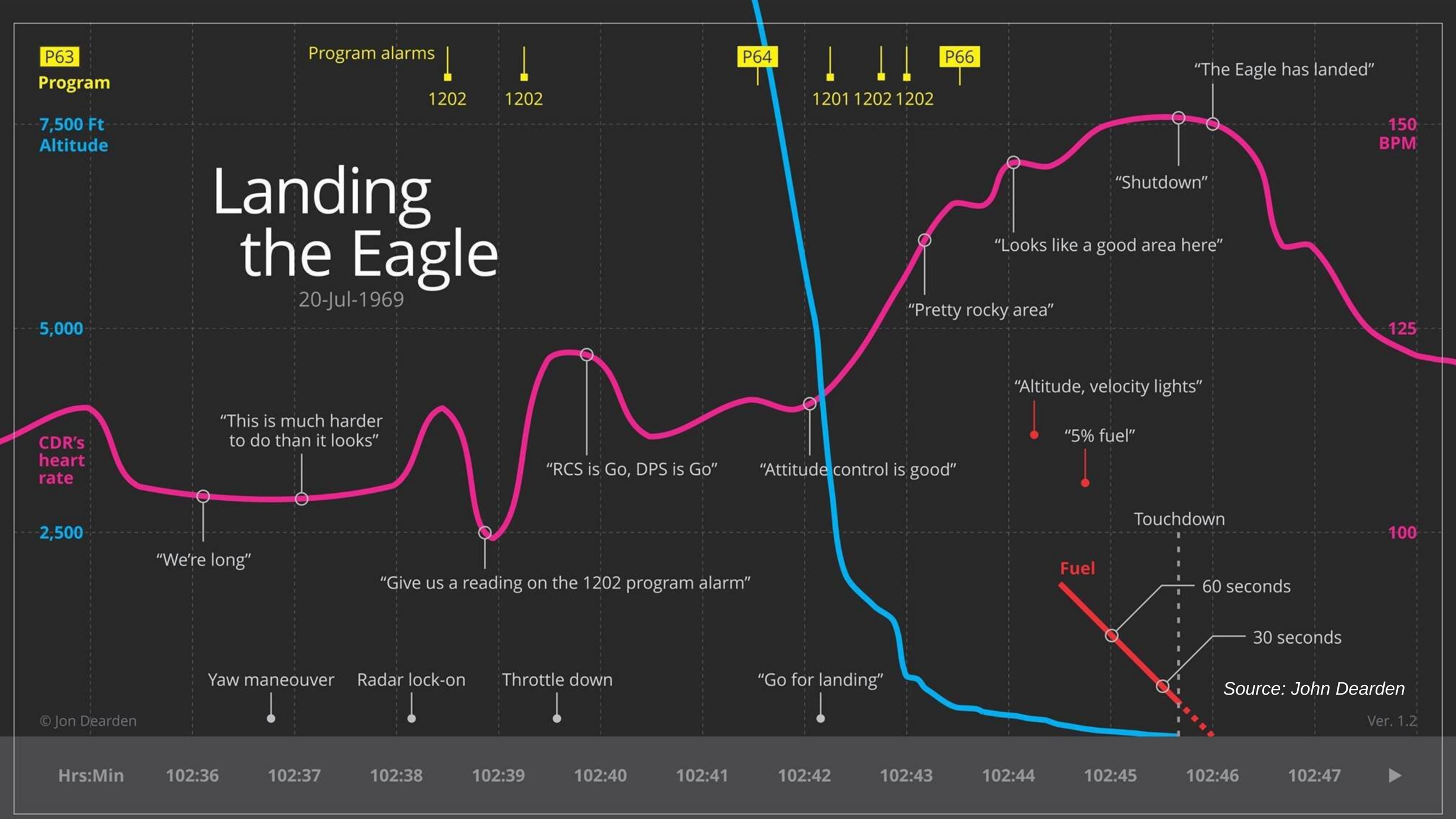
Jack Garman

APPLICABLE TO: IN DESCENT, AVERAGE-G ON

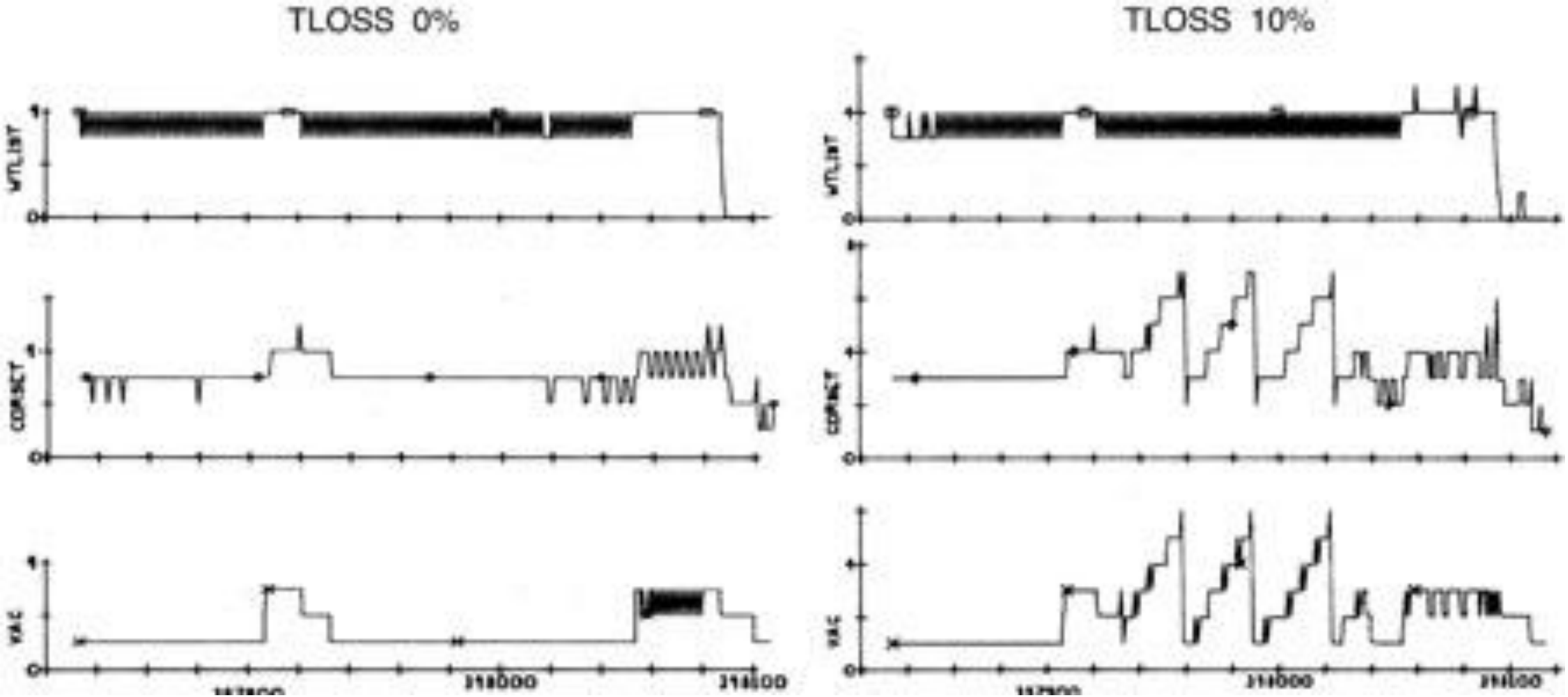
ALARM CODE		TYPE	PRE-MANUAL CAPABILITY	MANUAL CAPABILITY
01105	MK ROUT. BUSY	POODOO	PGNCS GUID. LOST, PGNCS/AGS ABRT/ABRT STG (decision how on current rules) (NO LR DATA)	PGNCS GUIDANCE NO/GO (PGNCS GO for TAPE METERS, CROSS-POINTERS, CONTROL, ABORTING) (NO LR DATA)
00430	CAN'T INTG. S.V.	"		
01103	CCSHOLE-PROG. BUG	"		
01204	NEG. WAITLIST	"		
01206	DSKY, TWO USERS	"		
01302	NEG. SQ. ROOT	"		
01501	DSKY, PROG. BAD	"		
01502	DSKY, PROG. BUG	"		
00607	LAMB. NO SOLN	"		
"O.F." = Overflow, to many - CONTINUING ← OCCURRENCE OF:			DUTY CYCLE MAY DESCEND PGNCS (AGS CONTROL MAY HELP - SEE BELOW) (WATCH FOR OTHER CUES) PGNCS CONDITION UNKNOWN, DSKY MAY BE LOCKED UP, DUTY CYCLE MAY BE UP TO POINT OF MISSING SOME FUNCTIONS (NAV, LAST TO DIE), SWITCH TO AGS (FOLLOW ERR NEEDLES) MAY HELP (REDUCES PGNCS DUTY CYCLE SIGNIF.)	SAME AS LEFT (except "other cues" which would otherwise be cause for ABORT PROBABLY ABRT, INSTEAD IT WOULD BE PGNCS GUIDANCE NO/GO — COMPLETE(?) NORMAL LANDING IN PGNCS.)
01104	DELAY ROUT. O.V.	BAILOUT		
01201	EXECT. O.F. (VAC)	"		
01202	EXECT. O.F. (JOBS)	"		
01203	EXECT. O.F. (TASKS)	"		
01207	EXECT. O.F. (MARKS)	"		
01210	TWO USERS	"		
01211	MRK ROUT. INTRPT	"		
02000	DAP O.F.	"		
ISS WARNING WITH:			PIPA/CDU/IMU FAIL DISCRETES PRESENT (Other mission rules suffice; alarm may help point to what rule will be broken)	same as left
00177	PIPA FAIL	LIGHT ONLY		
03777	CDU FAIL	"		
09777	PIPA, CDU FAIL	"		
07777	IMU FAIL	"		
10777	PIPA, IMU FAIL	"		
13777	CDU, IMU FAIL	"		
14777	PIPA, CDU, IMU FL	"		
00214	IMU TURNED OFF	LIGHT ONLY	AGS ABRT/ABRT STAGE	SWITCH TO AGS PGNS NO/GO on G&C (poss. NO/GO on NAV.)
01107	E-Mem. Destroyed	FRESH STRT	AGS ABRT/ABRT STAGE	SWITCH TO AGS PGNCS NO/GO! (IMU as ref. okay)
CONTINUING ← 00402	BAD GUID. CMDS	LIGHT ONLY	IF ALARM DOESN'T STOP: same as "POODO's" (ABRT.?)	IF ALARM DOESN'T STOP: Same as "POODOs"
CONTINUING ← 01406	GUID. NO SOLN	LIGHT ONLY	PGNCS GUID. NO/GO AS LONG AS ALARM OCCURRING (ATT. HOLD, CONST. GTC, CONT. OK) (ABRT WILL PROB. COME FROM CURRENT RULES e.g. GTC vs. V) WATCH GTC ←	Same as left (except prob. no abort.)
01410	GUID O.V.			

Echtzeitsysteme?




P63
Program
Program alarms
1202
1202
P64
1201
1202
1202
P66
"The Eagle has landed"
7,500 Ft
Altitude
150
BPM
Landing
the Eagle
20-Jul-1969
"Shutdown"
"Looks like a good area here"
"Pretty rocky area"
5,000
125
"Altitude, velocity lights"
"5% fuel"
"This is much harder
to do than it looks"
CDR's
heart
rate
"RCS is Go, DPS is Go"
"Attitude control is good"
Touchdown
2,500
100
"We're long"
Fuel
"Give us a reading on the 1202 program alarm"
60 seconds
30 seconds
Yaw maneouver
Radar lock-on
Throttle down
"Go for landing"
Source: John Dearden
© Jon Dearden
Ver. 1.2
Hrs:Min
102:36
102:37
102:38
102:39
102:40
102:41
102:42
102:43
102:44
102:45
102:46
102:47

Echtzeitsysteme?



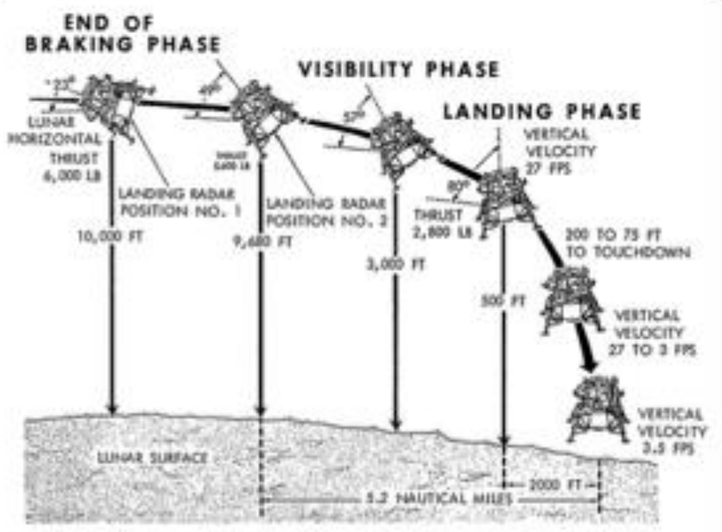
Source: Nasa

How a Small Real-Time Bug Endangered the Apollo 11 Mission

1. The Apollo 11 Mission

The NASA had in the 1960'ies and 70'ies a program named "Apollo" to bring men into space and onto the moon. The Apollo 11 Mission was the first to finally land on the moon. On July 20th 1969 at 20:17:58 UTC the first man made space vehicle landed and returned safely to earth with three astronauts on board.

During the approach with the LEM (Lunar Excursion Module) named "Eagle" the calculation of the correct flight path and control of the propulsion system was performed by the LGC (Lunar Guidance Computer). Mid way of approaching the moon the system reported two errors (#1201 and #1202) due to a timing problem in the LGC's program. This demo shall simulate the processes on the LGC and show how it came to the real-time errors. This is for demo purposes only and is based on the publicly available data published by NASA and others.



NOMINAL DESCENT TRAJECTORY
FROM HIGH GATE TO TOUCHDOWN

Source: Apollo 11 Press Kit - 06/26/69 - For the Apollo Lunar Surface Journal
Paper Capture by Ronald A. Wells - Restored version by Luigi Morielli
Original Bitmap Source Scans: KSC Library